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Research into Action to Benefit Canadians

Environment Canada's
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Research into Action to Benefit Canadians

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NWRI Scientific Assessment Report Series

The National Water Research Institute

The National Water Research Institute (NWRI) is Canada's largest freshwater research facility, with five locations across the country: at the Canada Centre for Inland Waters, Burlington, Ontario and the National Hydrology Research Centre, Saskatoon, Saskatchewan; and in Gatineau, Québec; Fredericton, New Brunswick; and Victoria, British Columbia. From these locations, NWRI leads initiatives in all regions of Canada and internationally to protect and sustain the quality and quantity of Canadian waters.

NWRI Scientific Assessment Report Series

On behalf of the Canadian government, NWRI leads and publishes scientific assessments of priority freshwater issues in Canada. Typically, these assessment reports are written by experts from NWRI, government, universities, and industry, and they encapsulate current scientific knowledge, trends, and information and program needs. As authoritative documents, they are intended to assist water science decision-makers, resource managers, and the research community in setting research priorities and in developing sound management policies and practices.

This report and previous ones in the series are available at www.nwri.ca

No. 1 - Threats to Sources of Drinking Water and Aquatic Ecosystem Health in Canada (2001)

No. 2 - National Assessment of Pulp and Paper Environmental Effects Monitoring Data (2003)

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Water Research to Benefit Canadians

Canadians pay for federal government research. Tax-payers foot the bill when Environment Canada scientists in red parkas gather samples from lakes high in the Arctic, or when research technicians in hip-waders collect sediments from urban ponds close to major highways to analyze for contaminants.

The Canadian public funds research to find out which substances are entering their lakes, rivers and wetlands, and what effects these might be having on aquatic organisms, or on drinking water. Canadian citizens pay to know if the water quality of the Great Lakes is improving and if climate change will affect how much water Canada will have. Enough for the future? Enough to support a competitive Canadian economy?

The Government of Canada has made a strong commitment to Science and Technology. Freshwater is a priority area and applied and relevant freshwater science ultimately helps ensure clean, safe and secure water for people and ecosystems. A key federal role is to provide scientific knowledge upon which decisions and sound policies and regulations can be based.

For more than 30 years, Environment Canada's National Water Research Institute (NWRI) has conducted water research to benefit Canadians. The Institute has led influential, multi-partner, national assessments of current and emerging threats to water quality, water quantity, and aquatic ecosystem health, producing the scientific knowledge now used by water policy- and decision-makers at all levels of government. Recognizing that water is essential to human health, key to the health of the environment, and vital to the economic strength and competitiveness of Canadian agriculture and industry, NWRI has become a world leader in freshwater issues.

As Canada's largest freshwater research institution, with more than 300 staff including aquatic ecologists, hydrologists, toxicologists, physical geographers, modellers, limnologists, environmental chemists and technicians working across Canada, NWRI has made major contributions to restoration of the Great Lakes, reductions in acid rain, regulation of toxic substances, creation of international atmospheric conventions, and has helped shape environmental management of Canadian freshwater resources, from the smallest stream to the largest watershed in Canada.

This report presents 11 stories describing past successes and work in progress - and there are many more yet to tell. It is about research that has given Canadians what they pay for: greater knowledge about threats to their water; practical, applied science that has supported and continues to support development of regulations, guidelines, policies and international agreements; and the tangible economic and health benefits that stem from sound stewardship of our aquatic resources.

Protecting the Environment from Acid Rain

2.5 million tonnes of sulphur dioxide were released to the Canadian environment in 2000.

Acidifying air pollution damages lakes, rivers, forests, soils, fish, wildlife and human health. Regulations put in force in the 1980s reduced emissions of gases such as sulphur dioxide and nitrous oxides. As a result, the water chemistry of some Canadian lakes has improved and biological revival has begun.

But the problem has not gone away. Experts predict that current and planned levels of reductions in emissions will not be enough to complete or sustain this biological recovery.

Further, scientists do not fully understand the processes of recovery from acidification, which are affected by many other environmental stresses such as droughts, increased ultraviolet radiation, and other changes in climate.

NWRI and Acid Rain

NWRI is a founding member of the Turkey Lakes Watershed Study, begun in 1980 as a "whole-ecosystem" research and monitoring program to understand the aquatic and terrestrial effects of acidic deposition. At this long-term ecological monitoring site, NWRI researchers and their partners continue to evaluate the hydro-geochemical responses of the watershed to atmospheric pollutants and other stresses such as climate change.

In 1997, NWRI joined with industry, the Government of Ontario and Laurentian University in a research initiative to work together to evaluate

the recovery of aquatic ecosystems damaged by acid rain in the Sudbury and Killarney region. Coordinated by the Freshwater Ecology Unit at Laurentian University, this collaboration is yielding promising results, encouraging hopes that a similar recovery from acidification can occur elsewhere in Canada and the world.

Over the past 20 years, NWRI scientists have evaluated data collected under the acid rain monitoring program in eastern Canada to make clear the extent and the rate of change of surface water acidification. This work has helped define the biogeochemical factors that control aquatic ecosystem responses to acidifying pollution.

NWRI research findings have figured prominently in major national assessment reports of aquatic effects of acid rain in 1985, 1990, 1997 and 2004. These have made significant contributions to government programs and strategies.

Impacts of NWRI Research on Decision Making

Scientific information produced by NWRI research plays an essential role in developing national programs and international agreements to reduce emissions of acidifying pollution. Without these, the release of atmospheric pollutants would continue unabated, to the detriment of the Canadian environment and the health of Canadians. As examples, NWRI research has contributed to:

- **Canada signing the United Nations Economic Commission for Europe (UN ECE) Convention on Long-Range Transboundary Air Pollution (LRTAP) in 1979;**
- **the domestic Acid Rain Control Program of 1985 that required a 40% SO_2 emission reduction from 1980 levels by 1994 in the seven easternmost provinces;**
- **Canada entering the UN ECE SO_2 Protocol in 1985, the UN ECE NO_x Protocol in 1988 and 1994, and, most importantly, the Canada-US Air Quality Agreement (AQA) in 1991, which established national and eastern emission caps and required an approximate 40% SO_2 emission reduction in the United States as well; and**
- **the 1998, federal-provincial-territorial governments signing of the Canada-Wide Acid Rain Strategy for Post-2000, which has a long-term goal of reducing acidifying emissions to meet critical loads.**

NWRI ongoing research strengthens the case for more stringent controls. Based on the findings of long-term monitoring studies and other regional assessments, researchers predict that without further controls, areas of southern and central Ontario, southern and central Québec, New Brunswick and Nova Scotia would continue to receive mean annual sulphate deposition amounts that exceed their critical loads, so that about 95,000 lakes would remain damaged by acid rain.

In total, without further controls, between 500,000 km^2 and 1,800,000 km^2 of southeastern Canada would receive harmful levels of acid rain.

Because of potential increases in acidifying emissions, the research effort has expanded into western Canada given concerns for some waters in southern British Columbia and northern Alberta, Saskatchewan and Manitoba.

Benefits to Canadians

Further controls would come with greater benefits, not only to the health of Canadian water resources, but to the health of Canadians. Sulphur dioxide can react with water vapour and other chemicals in the air to form very fine particles of sulphate, which form a key component of urban smog and are now recognized as a significant health hazard. Reducing emissions reduces health risks!

A 50% reduction in sulphur dioxide above the current commitments in the Eastern Canada Acid Rain Program and the US Acid Rain Program in both eastern Canada and the United States would bring many potential health benefits to Canadians. For example, it is predicted that:

- **550 premature deaths per year could be averted;**
- **1520 emergency room visits per year would be unnecessary; and**
- **210,070 asthma symptom days per year could be avoided.**

Economists estimate that society values these health benefits in a range from just under $500 million per year up to $5 billion per year.

Reducing Nutrient Impacts on the Environment

Each year, more than 304,000 tonnes of nitrogen and 12,000 tonnes of phosphorus enter Canada's ground and surface waters, and a further 1.4 million tonnes of nitrogen are released to the atmosphere, all as a result of human activity.

Nutrients are elements that occur naturally in the environment and are essential to the growth and survival of plants, humans and other living things: examples are nitrogen and phosphorus.

Nutrients entering the environment from human activities, however, have increased the abundance of biologically reactive forms of these elements - to the detriment of the environment.

Runoff from agricultural fields, urban expansion and municipal sewage all contribute nutrients to rivers and lakes, often over-stimulating plant production. This nutrient enrichment affects fish and wildlife, imposes a toxic threat to plants and animals, and poses a risk to human health.

Nutrients stimulate the growth of algae, including toxic algae. Drinking water containing toxins from toxic algal species can affect the health of terrestrial animals, including humans. Algae can also cause taste and odour problems in drinking water drawn from lakes and reservoirs.

Ammonia and nitrate, two forms of nitrogen, may also contaminate surface and ground waters. At high concentrations, both are toxic to aquatic and terrestrial animals. Nitrate has been identified as a possible contributing factor to a decline in amphibian populations, and ammonia discharges to fish kills.

In 1994, the Parliamentary Standing Committee on Environment and Sustainable Development reviewed the *Canadian Environmental Protection Act* (CEPA). They found that only one class of nutrient is currently regulated (namely phosphorus in laundry detergents) and that other nutrient classes and sources may be adversely affecting the environment.

NWRI and Nutrients and the Environment

The Government of Canada responded to these findings by conducting a cross-Canada study of nutrients derived from human activity to determine how they may be impairing Canadian ecosystems and affecting the quality of life and health of Canadians.

NWRI, as part of Environment Canada, led four other federal departments in this work, producing a national science assessment report in 2001. *Nutrients and their Impact on the Canadian Environment* concluded nutrients are indeed causing problems in certain ecosystems and affecting the quality of life for many Canadians.

Impacts include loss of habitat, fish kills, declines in amphibian populations, changes in biodiversity, contribution to acidification of soils and lakes, loss of recreational potential, and an increase across Canada in the occurrence of higher levels of nitrate in groundwater than those set out in drinking water guidelines.

Impacts of NWRI Research on Decision Making

The subject of nutrients in the environment has attracted considerable interest. To date, more than 2000 copies of the scientific assessment - *Nutrients and their Impact on the Canadian Environment* - have been distributed. Although it is difficult to track its impact on provincial and local policy and regulation, the findings have spurred several initiatives at the federal level to control the problem of nutrients in the environment, for example:

- total phosphorus has been added to the National Pollutant Release Inventory - the only legislated, nation-wide, publicly accessible inventory of its type in Canada;
- dissolved ammonia in water has been added to the *Canadian Environmental Protection Act* List of Toxic Substances, which will help to control its use;
- nutrient discharges are an important consideration in developing a national framework for better management of municipal wastewater in Canada; and
- nutrients are included as a component of Canada's new Agricultural Policy Framework - which is designed to make Canada the world leader in food safety, innovation and environmentally responsible production.

Benefits to Canadians

Ongoing NWRI research on nutrients, along with closer monitoring of nutrients in the environment and subsequent actions to manage them better will bring health and economic benefits such as:

- reducing concentrations of nitrogen oxides contributing to smog;
- lowering the risk to human and livestock health from toxic algal blooms;
- encouraging sustainable agricultural practices;
- protecting aquatic biodiversity and the health of aquatic ecosystems; and
- improving recreational waters and their economic potential through reduction in unsightly plant growth.

Pesticides - The Case of Tributyltin (TBT)

In the 2003 shipping season, there were over 3800 vessel transits through the Great Lakes-St. Lawrence Seaway System.

Tributyltin (TBT) is a pesticidal compound applied to the hulls of ships and small boats to protect against an accumulation of barnacles and other fouling organisms on underwater surfaces. TBT is one of a class of compounds called organotins and was introduced in the 1960s. Compared to earlier copper-containing antifouling coatings, TBT was more toxic to fouling organisms and lasted longer. Ships painted with TBT needed repainting every 4 to 5 years, as opposed to every 2 years for copper-painted ships.

Problems with TBT began to emerge in the 1970s and 1980s. It was shown to be extremely toxic to aquatic organisms other than those it was intended to target. Scientists concluded it was responsible for declines in oyster populations in France, and for adverse effects in certain marine snails. A notable effect was *imposex*, the imposition of male sexual characteristics on females of the species. This occurred at concentrations as low as, or lower than, 1 part per trillion.

NWRI and Tributyltin

NWRI research was the first in the world to demonstrate the occurrence and extent of TBT in the environment. Researchers mapped TBT contamination in water, sediment and aquatic biota across Canada; they determined its persistence, fate and environmental dynamics; and they assessed its risk to aquatic organisms.

Researchers concluded that TBT was present in the Canadian environment at concentrations that posed hazards to freshwater and marine life. The problem was especially acute in or adjacent to harbours, marinas and shipping channels.

Impacts of NWRI Research on Decision Making

NWRI research results were communicated to the Pest Management Regulatory Agency, the US Environmental Protection Agency (US EPA) and, internationally, to the Organotin Environmental Programme Association (ORTEPA).

NWRI research on TBT led to the first regulation of its use in antifouling paints in Canada in 1989. It was also influential in the US EPA regulation around that time.

When subsequent NWRI research indicated that the 1989 regulation was only partially effective in reducing TBT levels, a further regulation banning all antifouling uses of TBT was introduced in 2003 by the Pest Management Regulatory Agency.

NWRI research also led to the development of the International Maritime Organization (IMO) proposal to ban the application of organotin antifouling paints in 2003, and to ban their presence on ships by 2008.

Benefits to Canadians

The research that built the case for regulatory measures to phase out tributyltin as an antifouling agent has economic, environmental and human health benefits:

- **Food chain accumulation and bioconcentration have been demonstrated in crabs, oysters and salmon exposed to tributyltin oxide. TBT antifouling agents can be extremely toxic to aquatic organisms. Their phase-out will make a considerable contribution to protecting domestic and global water resources from their harmful effects and to safeguarding national and international fisheries - encouraging more environmentally acceptable and sustainable alternatives.**
- **The International Maritime Organization estimates that the international shipping industry is responsible for the carriage of 90% of world trade, with some 50,000 merchant ships trading internationally, registered in over 150 nations. Policies encouraging a total ban on TBT spur researchers to develop innovative anti-fouling agents less destructive to aquatic environments, and therefore more favourable to an environmentally sustainable shipping industry.**

Persistent Organic Pollutants - The Stockholm Convention

POPs are passed from mother to child mainly through breast milk. Levels of PCBs in the blood of some Inuit women are higher than Health Canada guidelines, and levels of certain POPs in breast milk have been found up to nine times higher than those in women who live in southern Canada.

Persistent organic pollutants persist! Therein lies the problem. Years after they have been banned, they can still be found in the environment - intact.

PCBs, DDT, toxaphene and dioxins are some of the pollutants in question. They do not break down easily and they accumulate in the fatty tissue of fish and animals. They also biomagnify, so that their concentration increases with each step in the food chain.

Most of the persistent organic pollutants (POPs) in the Canadian environment are a legacy of past uses within Canada and the northern United States.

They also continue to be transported in the atmosphere from distant sources in the southern United States, Mexico, Central America, Eastern Europe and Asia.

POPs tend to be found at high concentrations in top predators in Canada's North, though high levels are also found in fish and wildlife in the Great Lakes and St. Lawrence basin.

The geographic location and socio-economic activities of Aboriginal people in the North make them particularly susceptible because they eat traditional foods contaminated by these pollutants.

NWRI and Persistent Organic Pollutants

In the Canadian and circumpolar Arctic, NWRI scientists continue long-term research on the extent of persistent organic pollutants in the environment and their biological effects, for example:

- they are currently studying POPs in landlocked char fish in Resolute and Char lakes in the central Canadian archipelago, and collecting annual samples to follow changes over time;
- along a north-south transect in the Canadian Arctic, they use lake sediment cores to gain a better idea about the sources, long-range transport and impacts of new and old organic pollutants;
- to learn more about the behaviour of contaminants in high Arctic lakes, they developed a model and applied it to Amituk and Char lakes. Their results suggest that some Arctic lakes act as conduits, not sinks, for chemicals, with much of the annual contaminant loading from snowmelt exported from the lake in runoff water;
- NWRI scientists regularly visit small communities in the North to share the results of their research on POPs in fish and marine mammals with local residents;
- working with other experts in the international Arctic Monitoring and Assessment Programme, NWRI researchers contributed significantly to the scientific assessment of POPs in the circumpolar Arctic. The assessment report brought together all data available on organic pollutants in Arctic air, seawater, sediments, and terrestrial, freshwater and marine biota and gave governments of the eight Arctic countries a clearer picture of the state of the Arctic environment; and
- NWRI scientists also led the Canadian Arctic Assessment Report on POPs and mercury in fish and wildlife.

Impacts of NWRI Research on Decision Making

NWRI research helped prompt national and international recognition of the need for global action on POPs. Canada became the first country to sign and ratify the United Nations POPs Convention in 2001 - more commonly known as the Stockholm Convention (which entered into force on 17 May 2004).

This global agreement will reduce or eliminate emissions of twelve toxic substances known as the "dirty dozen," a group that includes PCBs, DDT, dioxins and furans.

Canada was the first country to commit specific funding to aid developing countries and those with economies in transition to build their capacity to deal with POPs. The Canadian Government provided $20 million to the Canada POPs Fund in March 2000.

Canada is also a signatory to the United Nations Economic Commission for Europe's POPs protocol that lists 16 chemicals (the Stockholm Convention 12 and 4 more) for a phase-out by countries of western Europe including Russia, and Canada and the United States.

Interestingly, much of NWRI's research expertise on the transport of POPs started with identifying the extent of contamination in the Great Lakes in the 1970s. This research became a significant contribution to Canada's Toxics Substances Management Policy, which preceded the Stockholm Convention by some 10 years. It was also instrumental in forging Annex 15 (on Airborne Toxic Substances) of the Great Lakes Water Quality Agreement, which calls for pollution control measures to reduce atmospheric deposition of toxic substances.

Benefits to Canadians

With its vast northern landscape, Canada is particularly vulnerable to the threats to human health and environmental security posed by persistent organic pollutants. A sustainable and prosperous northern economy ultimately depends on a safe and sustainable environment.

NWRI research directly benefited Canadians by playing an essential role in shaping the Stockholm Convention, a first step in protecting human health and the environment by dramatically reducing or eliminating emissions of some of the world's most hazardous chemicals. This international agreement has become a powerful tool in helping all countries maintain their domestic effort on POPs: fostering global action on a truly global problem.

NWRI research continues to benefit Canadians by producing vital scientific information on new POPs and their risk to the environment, information that will support further international, national and regional agreements and initiatives to protect the Canadian and global environment from the dangers of toxic chemicals.

Road Drainage -

Securing Public Safety, Economic Competitiveness and Enhancing Environmental Sustainability

When the hydraulics of the system are not well understood, a road drainage system can be "over-designed" - going beyond what is needed to function effectively and economically. This is costly to construct and maintain, and may prove harmful to the environment.

Effective road drainage is vital to road safety. Canadian drivers and the Canadian transportation industry rely on it. When road drainage systems do not function well, problems occur, for example:

- **too much water ponding on the surface, encroaching into driving lanes and endangering traffic safety;**
- **cold weather icing problems;**
- **erosion of drainage ditches;**
- **frost heaving of pavement slabs;**
- **risk of structural damage or failure of bridge decks;**
- **damage to the aquatic environment from contaminants washing off the road; and**
- **high costs of maintenance.**

Designing a good road drainage system depends on understanding the hydraulic operation of the system as a whole, including the role played by paved surfaces, gutters, median drains and various types of drainage inlets.

Over-designed elements can accelerate runoff, washing contaminants from the road surface and contributing to high and fast flows in drainage ditches susceptible to erosion.

NWRI and Road Drainage

In the early 1980s, NWRI joined with the Province of Ontario in a cost-recovery arrangement to develop a new design procedure for road and bridge deck drainage systems in Ontario.

NWRI could undertake this challenging task because of a unique blend of scientific and technical expertise in hydraulics/drainage and a specialized experimental facility in which a road section was constructed, then subjected to various drainage flows in a laboratory setting.

Researchers tested a full range of drainage design parameters, including road slopes, inlet locations, inlet grate arrangements (e.g., curb-parallel bars, diagonal bars, round grates, etc.), depressed and non-depressed inlet installations, and blockage conditions - all according to existing provincial and municipal design standards.

Their findings resulted in development of a new design procedure for road and bridge deck drainage, detailed in a Ministry of Transportation report.

Based on the wealth of new scientific information gathered from NWRI research, innovative concepts that reduced costs of road drainage were introduced, including:

- eliminating storm sewers (drains) on both sides of the peak of the road (where drainage is conveyed in surface gutters);
- increasing the spacing of inlet structures and manholes on a grade;
- recognizing that the grate inlet capacity was largely controlled by the gutter flow and no tangible benefits would be obtained by attempting to develop new grate designs; and
- providing a safer design for twin inlets. It had previously been thought that twin inlet capacities could be up to three times larger than those of single inlets. In NWRI tests, twin inlet capacities never exceeded those of single inlets by more than 70%.

Impacts of NWRI Research on Decision Making

The original hydraulic information produced by NWRI has remained the basis/standard of provincial road design since the early 1980s, and it is the core information in all drainage manuals produced by the Ministry of Transportation (MTO) since then.

NWRI is a member of the project team currently working on the latest update of the manual, with emphasis on environmental protection. Use of the manual is mandatory in all Ministry projects and in municipal projects involving MTO funding.

Building on the original project, NWRI research has moved on to address urban stormwater and highway runoff quality, impacts on receiving waters, and methods and technologies to lessen such impacts. Environment Canada has become a nationally and internationally recognized leader in this field.

Benefits to Canadians

The Ministry of Transportation of the Province of Ontario compared costs of road drainage design using the new NWRI procedure with costs using earlier methods and noted that the new procedure saved about $30,000 per kilometre of a four-lane road.

In a test year in the early 1980s, savings from use of the new procedure on all MTO projects amounted to more than $2 million.

For the last 20 years, provincial roads have been safer for vehicular travel, have had a reduced negative environmental impact on nearby aquatic ecosystems, and have cost taxpayers less - in large part thanks to the NWRI research that improved drainage design.

Taste and Odour in Drinking Water

It is important to pay attention to odour outbreaks because they can provide important clues about the health and safety of our water supplies. Short-term, they can signal treatment malfunction or chemical/biological hazards in the raw water. Long-term, they can provide an early warning of the decline in freshwater resources increasingly stressed by human activity.

We avoid water with an unpleasant taste and smell, which we instinctively link with disease and decay, and we question the fundamental safety of municipal drinking water that delivers bad taste to our tap.

The problem of bad taste and odour in our drinking water can increase the use of alternatives such as bottled and tanker-trucked water, which in fact may be less well regulated and stored. Ironically, bottled water consumption is highest, and increasing, in countries such as Canada, where we have the greatest collective access to treated water.

Most often, drinking water taste and odour is caused by potent organic compounds produced by organisms growing in the source water. The few toxicological studies of these compounds indicate that at the levels found in water supplies, they do not present a human health risk, although little is known about the long-term effects of consuming water that is repeatedly affected.

We have a very limited understanding of the environmental conditions that trigger many taste and odour episodes, making it difficult to predict when and where they will occur. Many taste and odour compounds are detectable at trace levels (parts per billion or even trillion) and require sophisticated analytical techniques to identify and monitor. Measures to remove them from drinking water in municipal water purification plants are usually expensive. Although some municipalities have implemented such controls, many cannot afford the cost, or are reluctant to commit large expenditures to treat such an unpredictable problem.

NWRI and Taste and Odour in Drinking Water

Taste and odour is a national concern, and a key focus of NWRI scientists. It is a highly complex problem that can be caused by one or more of numerous compounds produced by a diversity of organisms, and triggered and modified by different conditions.

Taste and odour has long plagued water supplies across the country, and in some more heavily developed water basins, consumer complaints are increasing. For example, the western basin of Lake Ontario provides drinking water to over 5 million consumers. In late summer of 1994, 1998 and 1999 the whole region suffered severe outbreaks of earthy-musty-smelling drinking water. Since then, these late summer events have continued to occur erratically.

Similar, more protracted muddy flavour affects water drawn from the Bay of Quinte and St. Lawrence River every year, and many waterbodies in the Prairies. These source waters differ tremendously in their physical, chemical and biological traits, yet are all afflicted by one or both of the same two odour compounds, geosmin and 2-methylisoborneol (MIB).

To learn more about th mechanisms that trigger such outbreaks, NWRI researchers are studying the production and environmental dynamics of these two highly potent compounds. Geosmin and MIB are produced in surface waters by bacteria - cyanobacteria (also known as blue-green algae) - and in some cases, *Streptomyces* (Actinomycetes). Geosmin, which has an earthy odour, is frequently produced by planktonic (free-floating) cyanobacteria. MIB, which has a mustier odour, is more often produced in the biofilms growing on rocks, aquatic plants and sediment. The two compounds are also produced by numerous bacteria and fungi in soil (and are in fact responsible for the characteristic smell of earth), and some drinking water odour can originate on land, caused by heavy soil runoff during storms or spring melt.

In 1999, NWRI joined seven major municipalities, the Ontario Provincial Government (Ontario Clean Water Agency and Ontario Ministry of the Environment) and two university partners to form the Ontario Water Works Research Consortium. This cooperative group, a unique model in Canada, was first established to address taste and odour problems in Lake Ontario and the St. Lawrence River, and in the past five years, has made substantial progress towards understanding and predicting these outbreaks. In 2000, scientists expanded their research program to investigate

the role played by large-scale water movements and shoreline nutrient inputs in recurring outbreaks.

NWRI is assessing the toxin levels and risks associated with blue-green algal blooms in areas of the Great Lakes such as Hamilton Harbour, the Bay of Quinte, lakes Ontario and Erie, and, farther west, prairie and rural source waters. Scientists are investigating possible links between development of these algal blooms and taste and odour outbreaks.

Impacts of NWRI Research on Decision Making

Much of the research effort is aimed at improving prediction of severe taste and odour problems in a given year. This helps regional and municipal governments develop their management options, and design control measures and programs to minimize taste and odour problems. Advance warning will also help water utilities to communicate effectively with their customers during severe outbreaks.

Already, researchers have found there is little taste and odour in the bottom waters of Lake Ontario, and municipalities are using or considering deep water intake, based on information provided by researchers in 2004.

This research can also be used to develop source-water protection strategies, increasingly mandated by provincial and territorial governments, and implemented by local agencies and watershed authorities.

Benefits to Canadians

Local governments are understandably cautious about implementing expensive taste and odour control measures at water purification plants, given that the ecological and environmental causes and impacts of the problem are not well understood. Nevertheless, municipalities are fully engaged with researchers at NWRI and the Ontario Water Works Research Consortium to develop a more complete understanding of causes so that control measures are successful and cost effective. But perhaps more importantly, this knowledge is essential to ensure improved public confidence in the source and safety of our drinking water.

Pharmaceuticals in the Environment - An Emerging Threat?

24,000 drugs are approved for human and veterinary use in Canada - some of these are being found in wastewater, agricultural runoff and drinking water.

Pharmaceuticals such as antibiotics, anti-inflammatories, analgesics and birth-control pills are used by millions of people and play an important role in modern health care. Judicious use of pharmaceuticals in agriculture helps production and advances economic competitiveness. However, recent studies in Europe and the United States, and now in Canada, have alerted us to the fact that these beneficial substances are entering the environment - with as yet unknown consequences.

The technology to test for trace amounts of drugs in water - at the part per trillion level, equivalent to one cent in 10 billion dollars - has only recently become available, and researchers have found pharmaceuticals, and personal care products like cosmetics and fragrances, in municipal sewage, agricultural and aquaculture wastes, and even in drinking water.

Recent media coverage of this emerging environmental problem has raised public concern but as yet there are no definite answers about risks to environmental and human health.

More research on a national and international scale is needed to determine the long-term ecological and human health consequences of continuous low-level exposure to these substances and to "mixtures" of these substances.

NWRI and Pharmaceuticals in the Environment

NWRI researchers are working with government departments, universities and international colleagues to develop and validate methods to measure pharmaceuticals in the environment and provide the scientific information needed to assess their risks.

In the Great Lakes basin, scientists are carrying out large-scale sampling of sewage treatment plants and receiving waters to determine whether certain human and veterinary pharmaceuticals and cosmetic compounds are discharged to the aquatic environment in concentrations that may pose a risk to aquatic life.

In the Prairies, NWRI is investigating the persistence of two antibiotics - spectinomycin and lincomycin - in liquid hog manure and in soil injected with liquid hog manure as a plant nutrient source. Researchers are assessing the potential for these antibiotics to be transported in surface runoff from cropland to groundwater.

A Trent University/NWRI study of pharmaceuticals in sewage treatment plant effluents of 14 Canadian cities was published in 2003, and NWRI and Health Canada have completed a survey of 20 southern Ontario drinking water facilities (water sources from lakes, rivers and groundwater) for nine acidic pharmaceuticals.

The results of these investigations confirm that some chemicals from pharmaceuticals and personal care products are present in wastewater effluent and in water supply sources, but it remains unclear whether these concentrations pose any risk to ecological (or human) health.

Impacts of NWRI Research on Decision Making

Pharmaceuticals and personal care products entering our water resources is an emerging environmental problem, so the decision-making process that results in protective measures is in its early stages.

The scientific information produced by NWRI research on the effects of such substances on aquatic ecosystems will feed into the process, and is already playing a supporting role in informing decisions to regulate and manage them.

One aim is to incorporate environmental considerations and safeguards into the pharmaceutical approval procedure, so that society can capitalize on the benefits provided by pharmaceuticals without compromising environmental health. Another is to improve the efficiency of our municipal wastewater treatment systems to remove these substances.

Benefits to Canadians

Although the research to support solutions to this problem is still in its early stages, it will ultimately bring environmental and economic benefits such as:

- improved public confidence in the quality of drinking water, as the precise levels in Canadian water supplies become clear and effective measures are put in place to reduce them if necessary;
- protection against adverse impacts on Canadian aquatic ecosystems and aquatic life, once sustained research has "teased out" which substance or mixture of substances is causing which effect and environmental management actions are targeted to particular offenders;
- continued public access to current and new pharmaceuticals, a necessity of modern health care, through an approval process that builds in environmental protection measures;
- development of new, potentially marketable technologies in the wastewater treatment industry to remove or reduce pharmaceutical and personal care substances; and
- environmentally sustainable and prospering pharmaceutical, cosmetics and agri-food industries that benefit consumers without endangering Canadian water resources, as research results are communicated and applied to producing solutions.

Zebra Mussels, Nutrients and the "Dead Zone" -

The Great Lakes Debate

Each mature zebra mussel can filter one litre of water a day. There are now enough zebra mussels in Lake Erie to filter the entire volume of the lake once a week. The U.S. Fish and Wildlife Service estimates the potential economic impact of the zebra mussel invasion at $5 billion over the next 10 years to American and Canadian water users within the Great Lakes region alone.

Lake Erie was declared dead in the popular media during the 1960s. It suffered from excessive growth of algae that led to obnoxious accumulations on shores, unsightly water and depletion of dissolved oxygen, which kills fish and other aquatic organisms.

More than 10 billion dollars were invested in the Great Lakes over the past 35 years, mostly in upgrades to sewage treatment plants to reduce phosphorus loads causing excessive production of algae. The Canada/United States Great Lakes Water Quality Agreement target of a 50% reduction in phosphorus load was achieved in the mid-1980s. Phosphorus concentrations dropped by half in the most affected west basin of the lake and the trend to worsening conditions throughout the lake was halted. Despite other benefits, however, and as predicted in NWRI reports of 1980, depletion of dissolved oxygen continues to be problematic.

But the plot thickens. In the last three years, stories have appeared in the media suggesting that zebra mussels have caused the return of what the media call the "Dead Zone" - depletion of oxygen at lake-bottom in Lake Erie.

Since their unintentional release into the Great Lakes ecosystem in 1986, populations of zebra mussels, a species alien to the Great Lakes, have exploded to such high levels that they cover most of the hard substrate of the lake and are spreading to soft sediment. The mollusks can remove a large portion of the plankton within water. This makes the water clearer, but it also alters the food chain, ultimately affecting the health of commercially valuable fish like whitefish.

Meanwhile, some Lake Erie fishing interests have suggested that phosphorus controls have decreased lake algal production excessively, causing a reduction in desirable fish species. They advocate that nutrient loads to the lake be increased.

At the same time, shoreline property owners are finding algae accumulations on their beaches. Increasing the phosphorus load would worsen this situation. Taken together, these occurrences constitute a complex environmental problem.

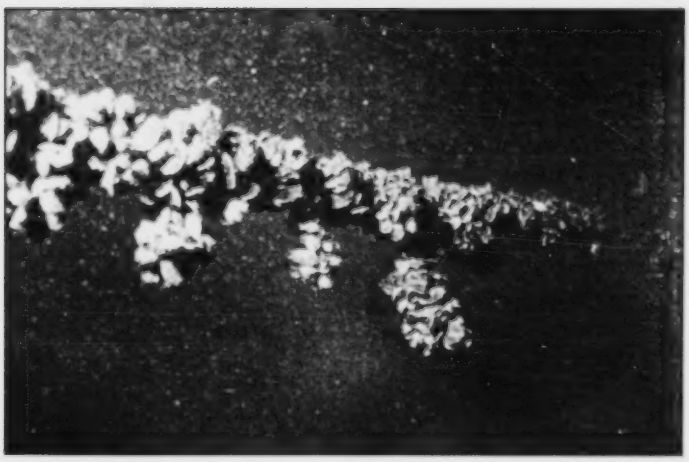
NWRI and Zebra Mussels, Nutrients and the "Dead Zone"

Researchers at NWRI, with several partners including Fisheries and Oceans Canada, the US Environmental Protection Agency, the US National Oceanic and Atmospheric Administration and universities, continue to investigate the impacts of alien invaders such as zebra mussels on Great Lakes' ecosystems - impacts that may have unforeseen consequences for human populations.

Their studies help determine how the condition and numbers of native species in Lake Erie are changing and how water quality and fisheries might be affected by changing nutrient conditions.

Long-term data indicate that phosphorus in the central and east basins of Lake Erie is not stable; in fact, there was a decrease in concentrations from 1992 to 1995, and an increase in 1996 and 1997. Environment Canada research suggests that increasing phosphorus could increase the presence of zebra mussels, but also that fluctuations in mussel populations could, in fact, be influencing phosphorus concentrations.

With 13 million people living around the lake, any action taken to alter nutrient inputs must be based on sound science. At this time, NWRI scientists are not recommending any change in policy.



Long-term monitoring has shown that lake-bottom oxygen levels have experienced considerable variation, and there is little evidence to suggest that zebra mussels are having any significant impact here. Researchers at NWRI have shown that weather is an important factor in explaining variations.

Ongoing research is vital to understanding the dynamics of this multifaceted problem: Lake Erie continues to react to the zebra mussel invasion and the 18 or so other alien species that have invaded since the mussels arrived.

Impacts of NWRI Research on Decision Making

Research results provide the scientific information required

- to decide any future changes needed in nutrient inputs to the Great Lakes, which helps meet and sustain international obligations under the Canada/United States Great Lakes Water Quality Agreement;
- to identify where and what kind of environmental monitoring is required to protect the Great Lakes - St. Lawrence River ecosystem;
- to provide the scientific base for development of an Invasive Alien Species Strategy for Canada; and
- to communicate reasonable expectations of lake water quality based on understanding how the lake works.

Benefits to Canadians

This research brings health, environmental and economic benefits to Canadians.

Nutrients from sewage continue to affect beach use in the Great Lakes. A better understanding of the impacts of nutrients on the ecosystem can help lake management agencies take prompt action to avert the need for beach closures, yielding more and healthier recreational (swimming) opportunities.

Understanding the oxygen situation has allowed research to be focused on more important questions such as how much the mussels have altered the processing of nutrients and whether this requires a further reduction in phosphorus load.

The overpopulation of zebra mussels has caused environmental disruption and disturbances in the food chain. For example, populations of Diporeia – an important source of essential fatty acids for fish – have diminished drastically in Lake Erie. In turn, this has affected the health of commercial fish, which affects the economic strength of the fishery.

With an estimated 162 new invasive species found in the Great Lakes as of 2001, the threat to the ecological integrity of one of Canada's world-famous natural ecosystems continues to grow. Research and monitoring that supports environmental strategies to protect the Great Lakes from this threat will continue to benefit the Canadian environment and economy.

Flame Retarding Chemicals - A Cause for Environmental Concern

In Canada, levels of PBDEs in human milk have increased by a factor of ten between 1992 and 2002 and by a factor of around 100 since the early 1980s, according to a recent Health Canada study.

Brominated flame retardants (BFRs) protect against the dangers of fire and are present in everyday items such as textiles, plastics, paints, televisions, computers and other electrical appliances.

Polybrominated diphenyl ethers (PBDEs) are the most widely used brominated flame retardant. They became a cause of international environmental concern in the late 1990s when a study in Sweden showed that in contrast to contaminants such as PCBs, levels of PBDEs in samples of human milk had increased exponentially since the early 1970s.

BDE (brominated diphenyl ether) molecules are similar in structure to polychlorinated biphenyls (PCBs), which are classified as probable carcinogens and are known to cause birth defects, neurological damage and thyroid imbalances.

NWRI and Flame Retarding Chemicals

NWRI scientists are leading international efforts to understand the sources, environmental behaviour and toxicity of brominated flame retardants. They work with experts from other countries to share research knowledge and help build a global picture of the extent of PBDEs in the environment.

BFRs from industrial activities in the south are transported north mainly by atmospheric processes and enter aquatic ecosystems when snow and ice melt in the spring. As part of the federal government's Northern

NWRI has organized and hosted four, and played key roles in other, multi-sector international research workshops in the field of brominated flame retardants – indicative of the tremendous research and public policy interest in BFRs as a global environmental pollutant.

Contaminants Program, NWRI conducted studies to determine the presence and extent of brominated diphenyl ethers in Arctic air.

Building on a comprehensive report on contaminants in sediments across the entire width of the Great Lakes basin, NWRI is now working with partners to track trends of new and emerging chemicals including brominated flame retardants in the Great Lakes.

Collaborating with Fisheries and Oceans Canada, Health Canada, other members of Environment Canada, and the universities of Guelph and Trent, NWRI carried out a multi-year investigation of the impact of PBDEs in Canada. They examined samples of breast milk, foods, biota, avian eggs, sediment and air from different parts of the country. They also investigated the occurrence of the chemicals in Canada's wildlife. Their findings confirmed that PBDEs are a ubiquitous pollutant, on the rise in Canada.

Impacts of NWRI Research on Decision Making

NWRI was a co-leader of the Arctic Monitoring and Assessment Programme (AMAP) Report on Persistent Organic Pollutants. This assessment gives a comprehensive review of contamination of the Arctic environment and underlines the increasing concentrations of flame retardants and other new contaminants in marine and freshwater animals. The Arctic Monitoring and Assessment Programme's primary function is to advise the governments of the eight Arctic countries - Canada, Denmark/Greenland, Finland, Iceland, Norway, Russia, Sweden and the United States - on threats to the Arctic region from pollution, and help direct their efforts to take remedial and preventive actions.

The information gathered across Canada by NWRI researchers contributed to a risk assessment under the *Canadian Environmental Protection Act* (CEPA), which proposes that all PBDEs be considered persistent, bioaccumulative, and toxic as defined in the Act and that certain PBDEs be considered for inclusion on the Virtual Elimination List.

The research results have also been used in international risk assessment and management programs for brominated diphenyl ethers and other BFRs. For example, NWRI is contributing to the United Nations Economic Commission for Europe's (UN ECE) Task Force on Persistent Organic Pollutants (POPs), and the Working Group on Strategies and Review, which has a major policy role in revising existing protocols and preparing new ones.

Benefits to Canadians

Sound science benefits Canadians! Without it, assessments of the risk to the Canadian environment from industrial chemicals such as PBDEs could not be carried out.

Risk assessments help identify the sources of pollution that pose the greatest risk to the environment and human health, and are the prelude to actions to control them, actions that help reduce an increasing number of human health issues such as birth defects, neurological damage and thyroid imbalances.

In providing the science for the risk assessment that recommended PBDEs be recognized as toxic, NWRI played a vital role in the process that ultimately results in regulations, guidelines and other tools to manage the risks posed by these substances - the process that will prevent pollution and protect environmental and human health.

Quenching the Peace-Athabasca Delta

The Peace-Athabasca Delta is located in the south-east corner of Wood Buffalo National Park, one of Canada's largest national parks. It is a RAMSAR wetland and a UNESCO World Heritage Site.

The Peace-Athabasca Delta in northern Alberta is one of the world's largest inland freshwater deltas and a wetland of international importance. It is home to some of the largest undisturbed grass and sedge meadows in North America, and it provides habitat for large populations of waterfowl, muskrat, beaver and free-ranging wood bison.

Over the past 25 years, this complex and dynamic region has undergone several prolonged dry periods that have turned some basins from aquatic into terrestrial ecosystems. The first came after the construction and initial filling of the W.A.C. Bennett hydroelectric dam at the headwaters of the Peace River, between 1968 and 1971, and the second after the retreat of a major spring flood in 1974.

Lack of regular flooding is the main problem. Without an abundant supply of water in areas dependent on overflow, it is difficult for wetlands to sustain themselves. Unlike urbanized areas to the south where spring flooding caused by river ice jams often wreaks havoc on property and the economy, flooding in this remote northern part of Canada spurs the high biological productivity and sustains the "natural capital" for which the Delta is famous.

NWRI and the Peace-Athabasca Delta

NWRI is conducting research to learn more about the hydro-climatology and ecology of the Delta, and the effects that changes in climate might have on its productivity and biodiversity.

To meet the challenge of gathering information over such a huge and remote region, NWRI is developing innovative tools - such as new remote sensing techniques - to comprehend the spatial dimension of floods, water levels and changing flow regimes in the region.

By analyzing historical satellite imagery showing past water-level fluctuations, scientists have improved their understanding of evapotranspiration and other hydrological processes, and have gained information to use in water-balance models to help predict future changes.

In the 1990s, NWRI played a major role in a provincial-territorial-federal initiative, the Northern River Basins Study. Researchers found that some effects of the flow regulation necessary for dam operations, combined with large variations in climate, had reduced the occurrence of massive ice jams that cause flooding in the Delta.

Once NWRI scientists understood how changes in flow, along with climate variation were contributing to these prolonged dry periods, they were able to develop a strategy that maximized the potential for flooding. Their strategy timed flow releases from the W.A.C. Bennett hydroelectric dam to coincide with favourable natural conditions, such as predicted from the size of the snowpack. Flow released from the upstream dam would thereby augment the size of the natural floodwave produced by snowmelt runoff from all the other tributary flow sources.

Impacts of NWRI Research on Decision Making

NWRI recommended that the flow regulation of the Peace River be slightly modified to help increase the opportunity for ice jam flooding during the spring. BC Hydro agreed. In the spring of 1996, hydrological and climatic conditions were appropriate, and a timed flow release by dam managers increased the magnitude of an ice-jam flood - bringing water to areas that had been dry for more than two decades.

Subsequent NWRI research under the Northern Rivers Ecosystem Initiative, another multi-partner program, showed that the flow augmentation significantly contributed to the ice-jam flooding of the Delta that year – the first major flood in almost 20 years. Moreover, researchers found that under future climate change, with its greater rates of drying, the health of the Delta would become increasingly dependent on such floodwater.

Benefits to Canadians

Environmental and socio-economic benefits to Canadians can result from use of this augmentation strategy, which enables water managers to make adaptations that can reduce the negative effects of climate change on northern water resources.

Assisting the periodic flooding vital to the continued good environmental health of the region helps safeguard its world renown as a natural heritage site. It also protects and sustains the natural resources on which local aboriginal communities depend for their livelihood and their way of life.

Sediment Remediation Technology

Between 1993 and 2001 around US$130 million was spent for sediment remediation within the Detroit River/Lake Erie basin, removing some 843,500 cubic metres of contaminated sediment and an estimated 198,000 kg of PCBs.

Years of pollution by waste from sewage, pulp and paper mills, the steel and petroleum industries, and other sources have contaminated the sediment of many of the world's harbours, lakes, rivers and canals.

Contaminants in bottom sediments can be released into the water above, to the detriment of water quality and aquatic organisms. Pollutants from sediment can accumulate in the food chain, endangering fish and birds, and ultimately humans too.

The conventional way of dealing with contaminated sediment is to *dredge* it – scoop it up and haul it away for long-term storage and possible treatment. But dredging is not always feasible if the sediment is unstable or if the water is too deep, and the process may fail if all the sediment cannot be removed.

Dredging and disposal of contaminated sediment are not only extremely expensive but can pose a risk to environmental and human health. The high cost of the *remove-and-treat* option has driven the need for more innovative technologies.

NWRI and Sediment Remediation Technology

In pursuit of a better technology to detoxify sediments, NWRI conducted extensive laboratory tests of different *in situ* methods, followed by trials in the field. *In situ* treatment has advantages over dredging, as the sediment is treated in its current location, not removed at great expense to be treated elsewhere. With *in situ* sediment treatment, chemicals are injected directly into the sediment at the bottom of a river or harbour.

These tests and trials produced one of the first commercialized on-site remediation processes. The Limnofix *In situ* Sediment Treatment Technology (LIST) uses an underwater harrow towed behind a boat to till contaminated sediment and inject it with a chemical oxidant, usually calcium nitrate.

The injected oxidant promotes biodegradation of contaminants, breaking them down by providing oxygen to the bacteria in the sediment and

oxidizing the sulfides that hold back this natural process.

Although oxidization takes place relatively quickly, bioremediation can take several months – depending on the type and severity of the contamination.

In demonstrations in Canada, the United States and Europe, NWRI scientists have successfully shown that *in situ* treatment can enhance biodegradation, oxidize sulfides, and reduce sediment toxicity, so that water quality improves and aquatic habitat is healthier. Costly dredging, with its environmental risks, can be eliminated in some cases.

Impacts of NWRI Research on Decision Making

National and international environmental management agencies and governments have decided to use *in situ* de-tox methods to restore contaminated sediments:

- some of the larger Great Lakes' ports have zones highly polluted by sulfides, heavy metals, PCBs and phosphorus from municipal and industrial discharges. NWRI and partners were asked to implement *in situ* sediment treatment for a range of contaminants;
- near the old airport in Hong Kong, sewage-contaminated sediment in the marine environment was causing serious odour problems and corroding nearby buildings and aircraft. A full-scale treatment was carried out and within weeks, the sediment had turned from black to brown, more than 95 per cent of the sulfides were remediated, and the odour had dissipated significantly;
- in the late 1990s in Salem, Massachusetts, a mudflat contaminated with coal tar from a coal gasification plant underwent two LIST treatments using an injection system towed behind a tractor at low tide. It is now 90 per cent restored. LIST has also been accepted by the United States Naval Facilities Engineering Service Center to clean up some American naval sites;
- NWRI, with worldwide licensee, Redlog Environmental Ltd., demonstrated the effectiveness of *in situ* bioremediation for sediments contaminated with oil from the 1991 Gulf War. This work was used to support claims to the United Nations Compensation Committee by Kuwait against Iraq stemming from the Iraqi invasion of Kuwait; and
- a full-scale application of the remediation technology was used to eliminate odours from the Shing Mun River in Hong Kong. This application was successful and the second full-scale treatment of the river has been recently completed.

Benefits to Canadians

Sediment remediation technology is a classic example of good environmental practice making sound economic sense!

- the technology reduces toxicity in the environment, without risking the kind of environmental damage that can result from dredging;
- this environmental benefit is achieved at a lower financial cost, making the better environmental practice the more cost-effective one; and
- the interest in the technology in Canada and abroad indicates a considerable market potential, increasing Canada's economic competitiveness in environmental technology development.

Key Scientific Publications

A small selection of key publications related to subjects dealt with in this report are provided below. NWRI scientists have been instrumental in all of them either as authors, editors or as research team leaders.

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Environment Canada. 2005. 2004 Canadian Acid Deposition Science Assessment [CD-ROM].

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